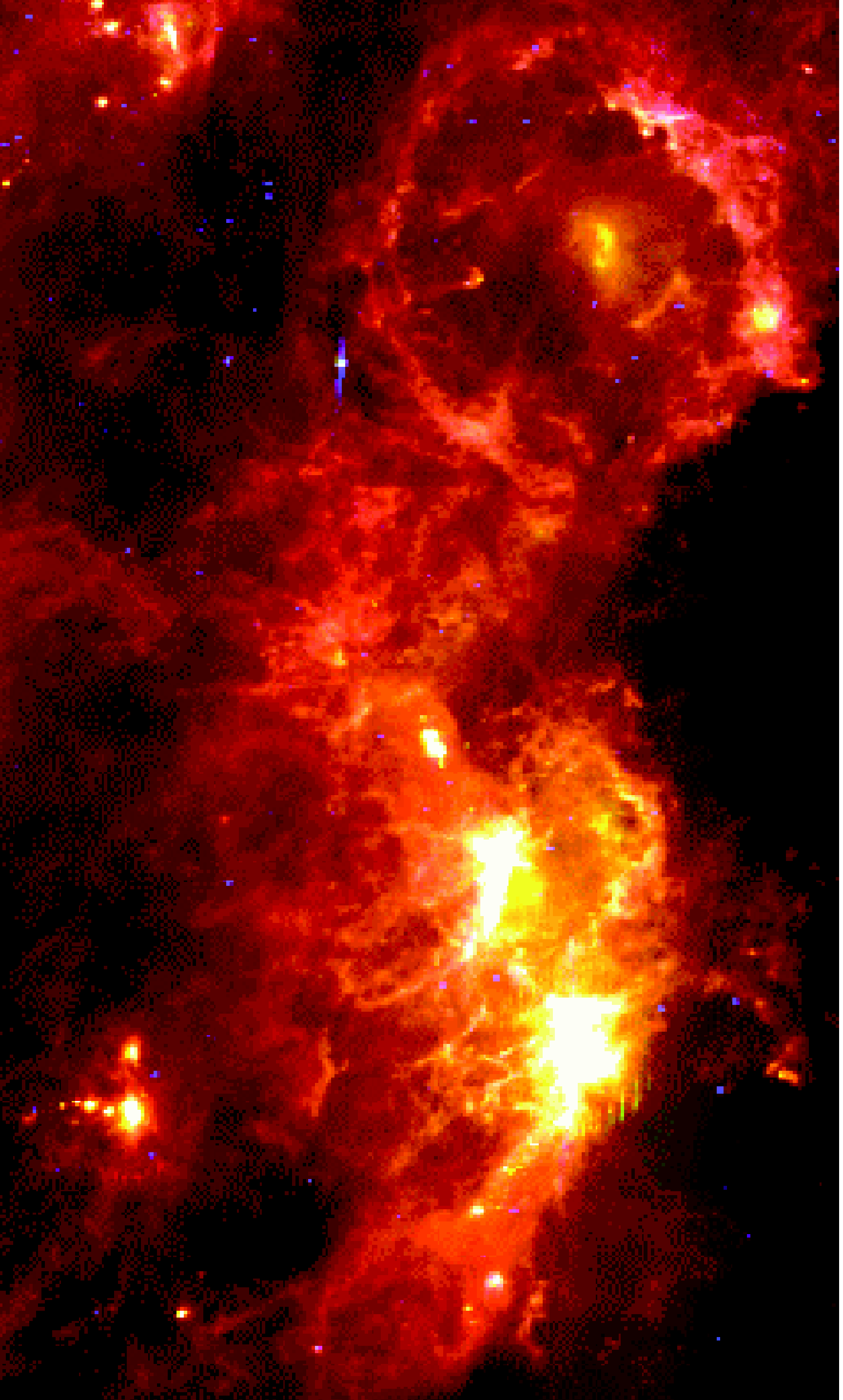


Analysis of samples returned by space missions : Apollo, Genesis, Stardust, Marco Polo

Bernard Marty

Centre de Recherches Pétrographiques et Géochimiques, UPR2300 CNRS

Ecole Nationale Supérieure de Géologie

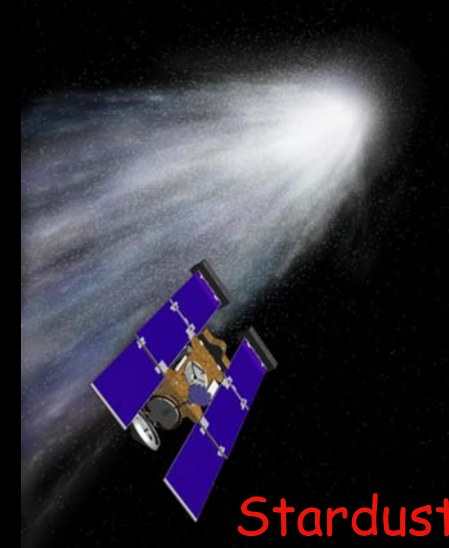
Institut Universitaire de France

Why should we return samples from space ?

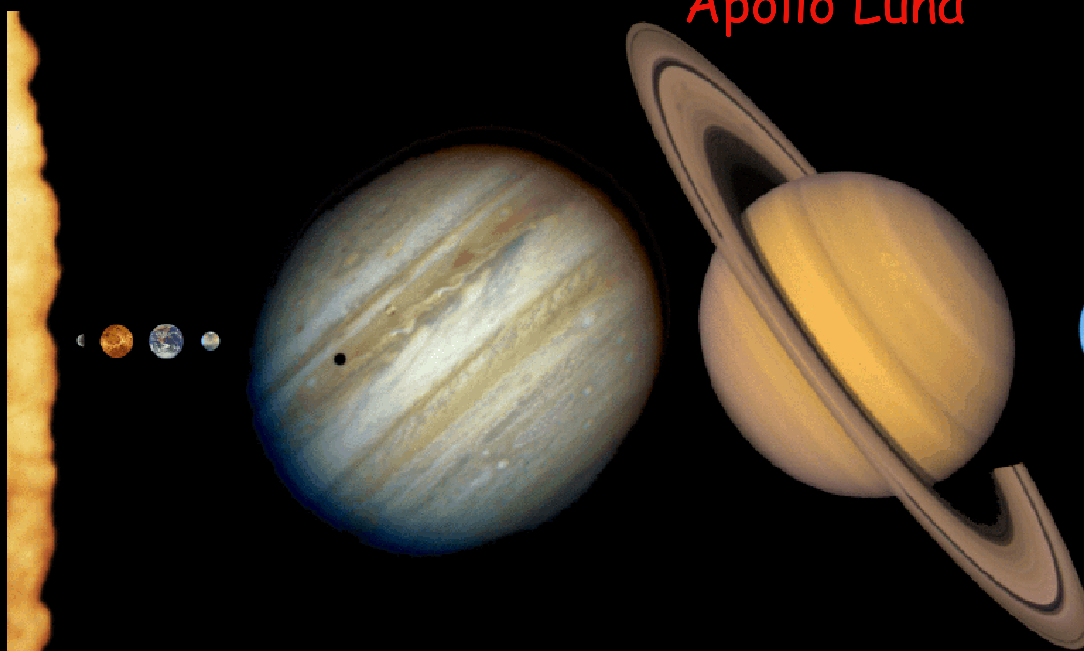
Grand questions on solar system formation and planetary evolution

Genesis

Apollo Luna

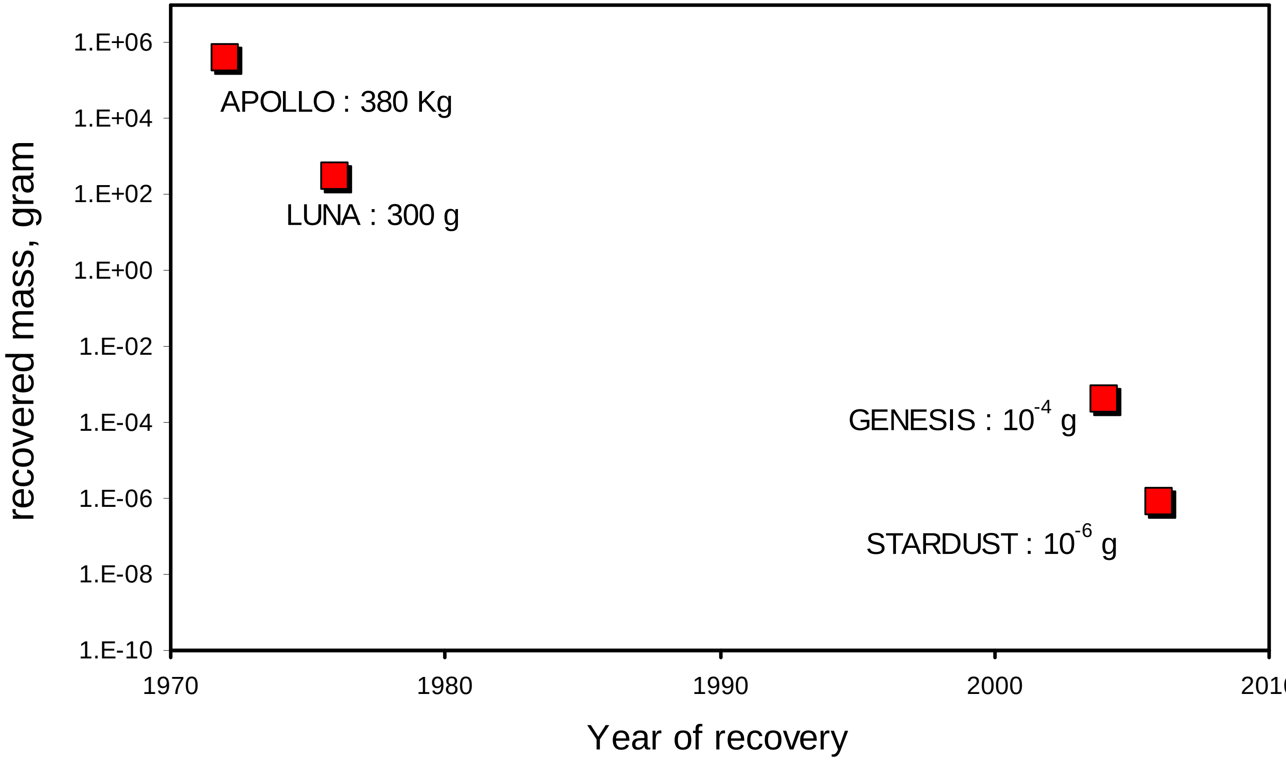


Stardust

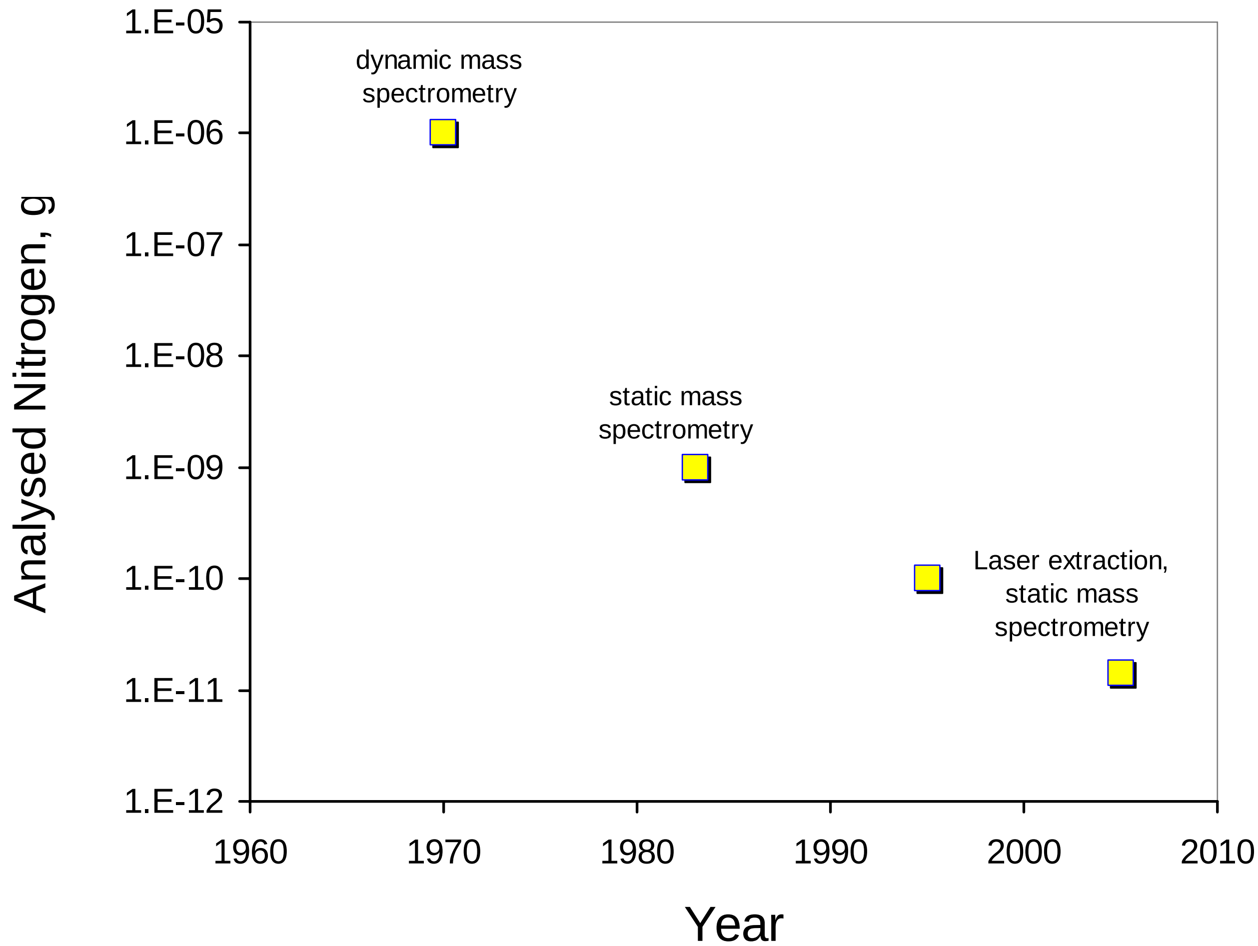


Origin of matter
Formation processes
Chronology

Amount of samples returned by space missions



Amount of nitrogen requested to carry an isotope analysis at the per mil precision level



Top Ten Scientific Discoveries Made During Apollo-Luna Exploration of the Moon

1. **The Moon is not a primordial object; it is an evolved terrestrial planet with internal zoning**

2. **The Moon is ancient and still preserves an early history (the first billion years) that must be common to all terrestrial planets.**

3. **The youngest Moon rocks are virtually as old as the oldest Earth rocks.**

4. **The Moon and Earth are genetically related and formed from different proportions of a common reservoir of materials - Oxygen isotopes**

5. **The Moon is lifeless; it contains no living organisms, fossils, or native organic compounds.**

6. **All Moon rocks originated through high-temperature processes with little or no involvement with water. Three types: basalts, anorthosites, and breccias.**

7. **Early in its history, the Moon was melted to great depths to form a "magma ocean." The lunar highlands contain the remnants of early, low density rocks that floated to the surface of the magma ocean.**

8. **The lunar magma ocean was followed by a series of huge asteroid impacts that created basins which were later filled by lava flows.**

9. **The Moon is asymmetrical, possibly as a consequence of its evolution under Earth's gravitational influence. Its crust is thicker on the far side, while most volcanic basins -- and unusual mass concentrations -- occur on the near side.**

10. **The surface of the Moon is covered by a rubble pile of rock fragments and dust, called the lunar regolith, that contains a unique radiation history of the Sun**

Composition of outer solar system : Stardust

NASA Program *Discovery*
PI : Don Brownlee

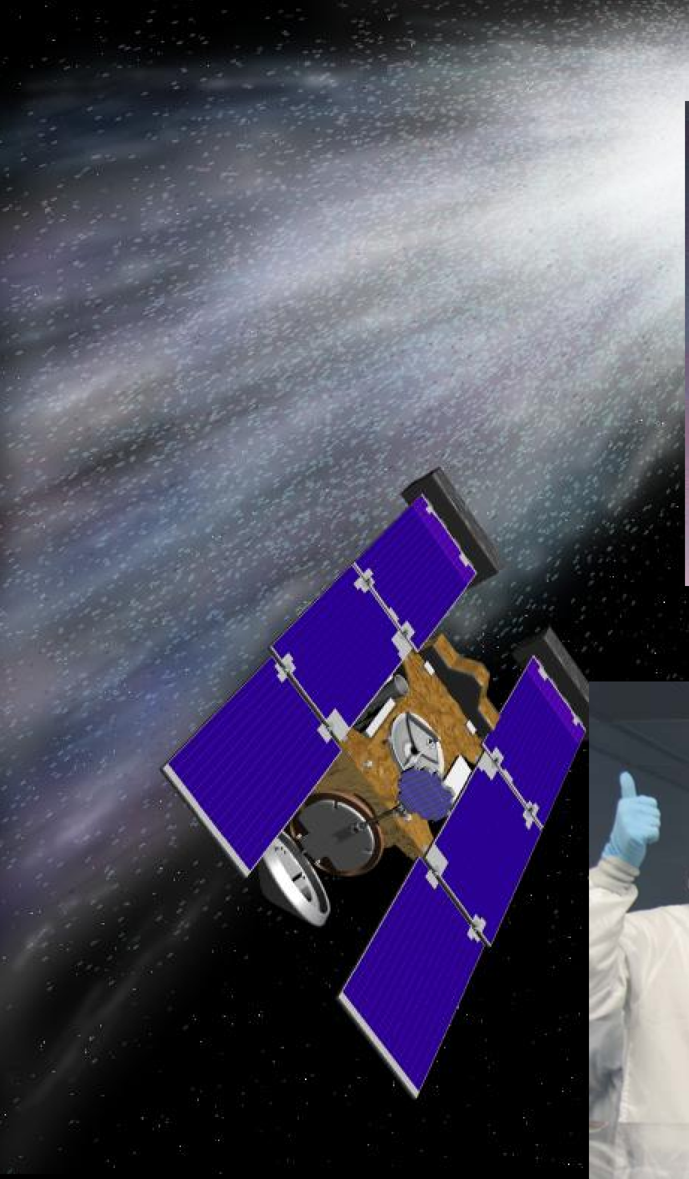
Questions

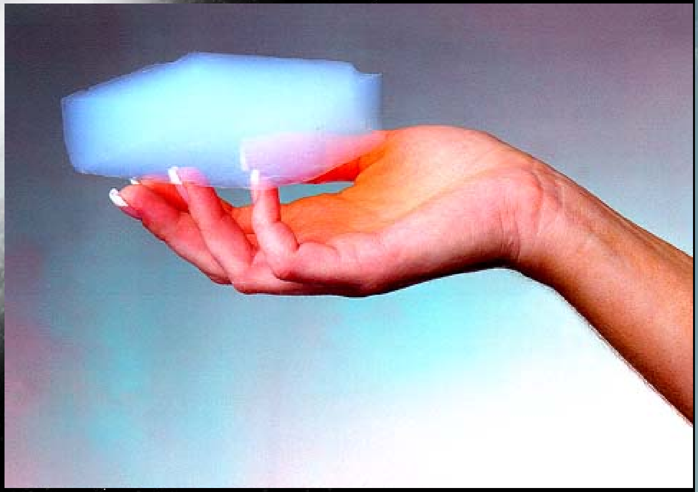
Is cometary matter solar or interstellar ?

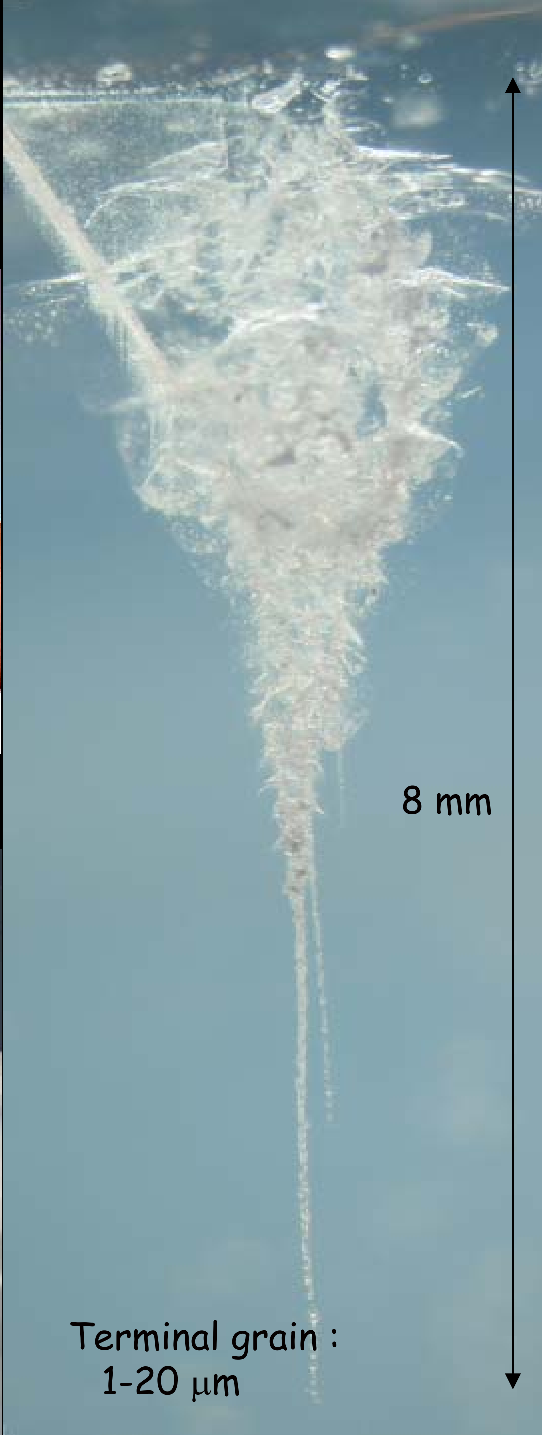
Do we have already cometary matter on Earth (e.g., IDPs) ?

Relation between comets and atmospheres ?

Stardust sampled grains from comet Wild2/P at a differential velocity of 6.1 km/s and returned them to Earth on Jan. 15, 2006

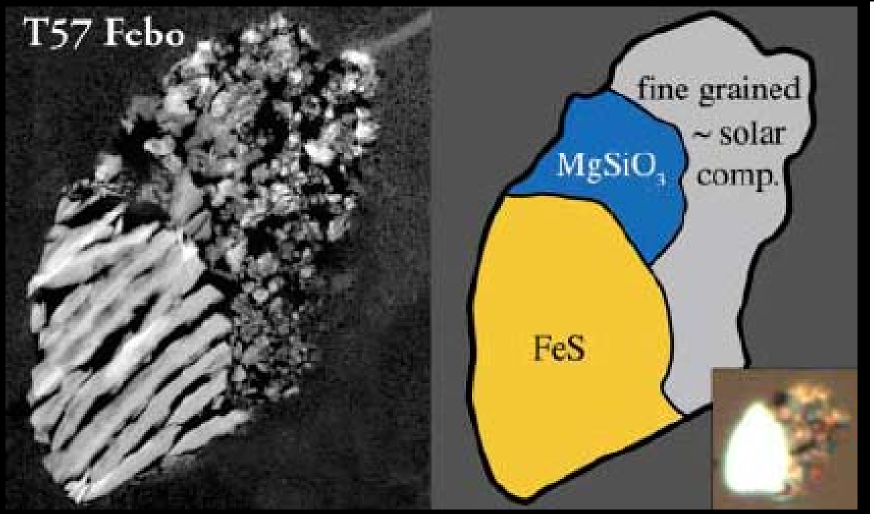




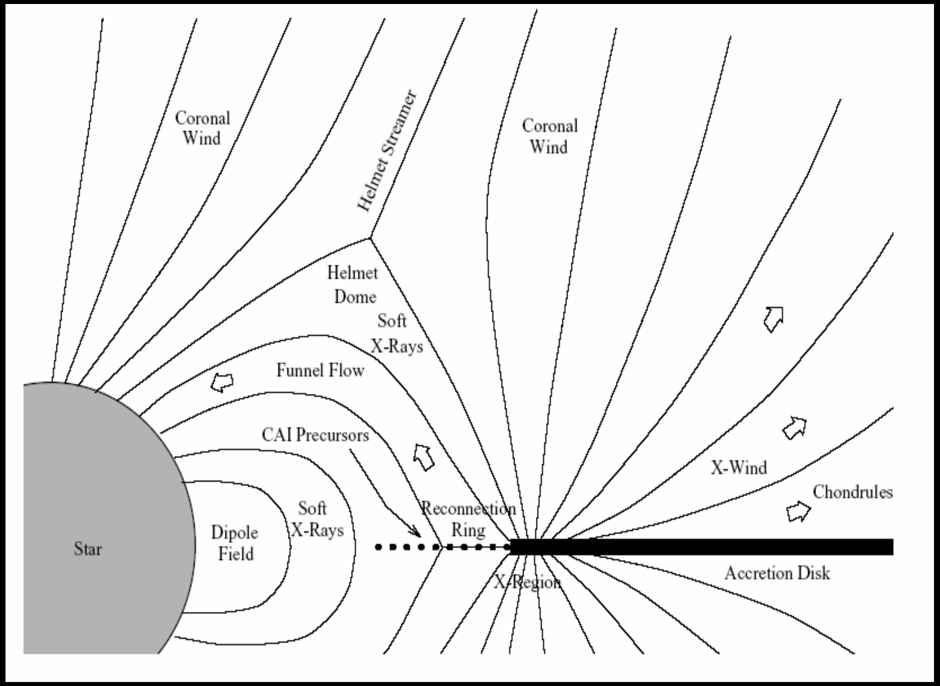


The composition of Stardust grains resembles strongly to that of primitive meteorites, including refractory phases (Mg-rich olivine, CAIs) : requires large-scale mixing in nascent solar system

Grains rich in chondritic noble gases : possible contribution to planetary atmospheres (e.g., LHB on Earth)



Brownlee et al., 2006; McKeegan et al., 2006



Shu et al., 1996

GENESIS
SEARCH FOR ORIGINS

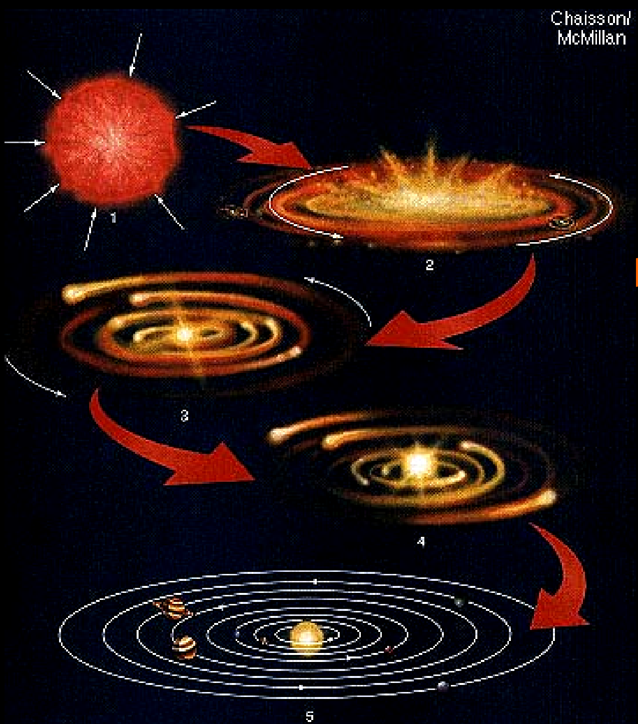
What was the composition of the Solar nebula ?

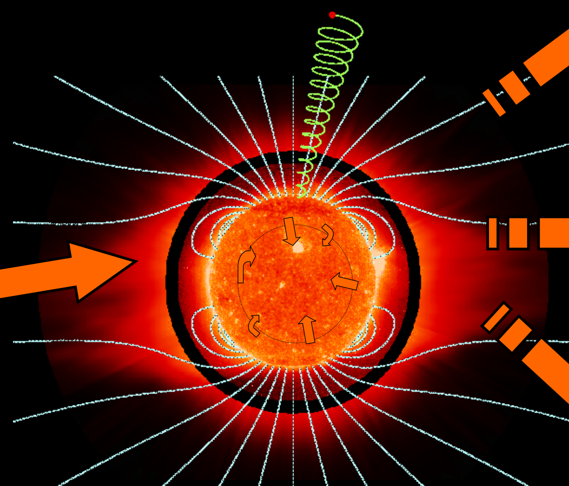
Mission priorities :

1- Oxygen isotopes

2- Nitrogen isotopes

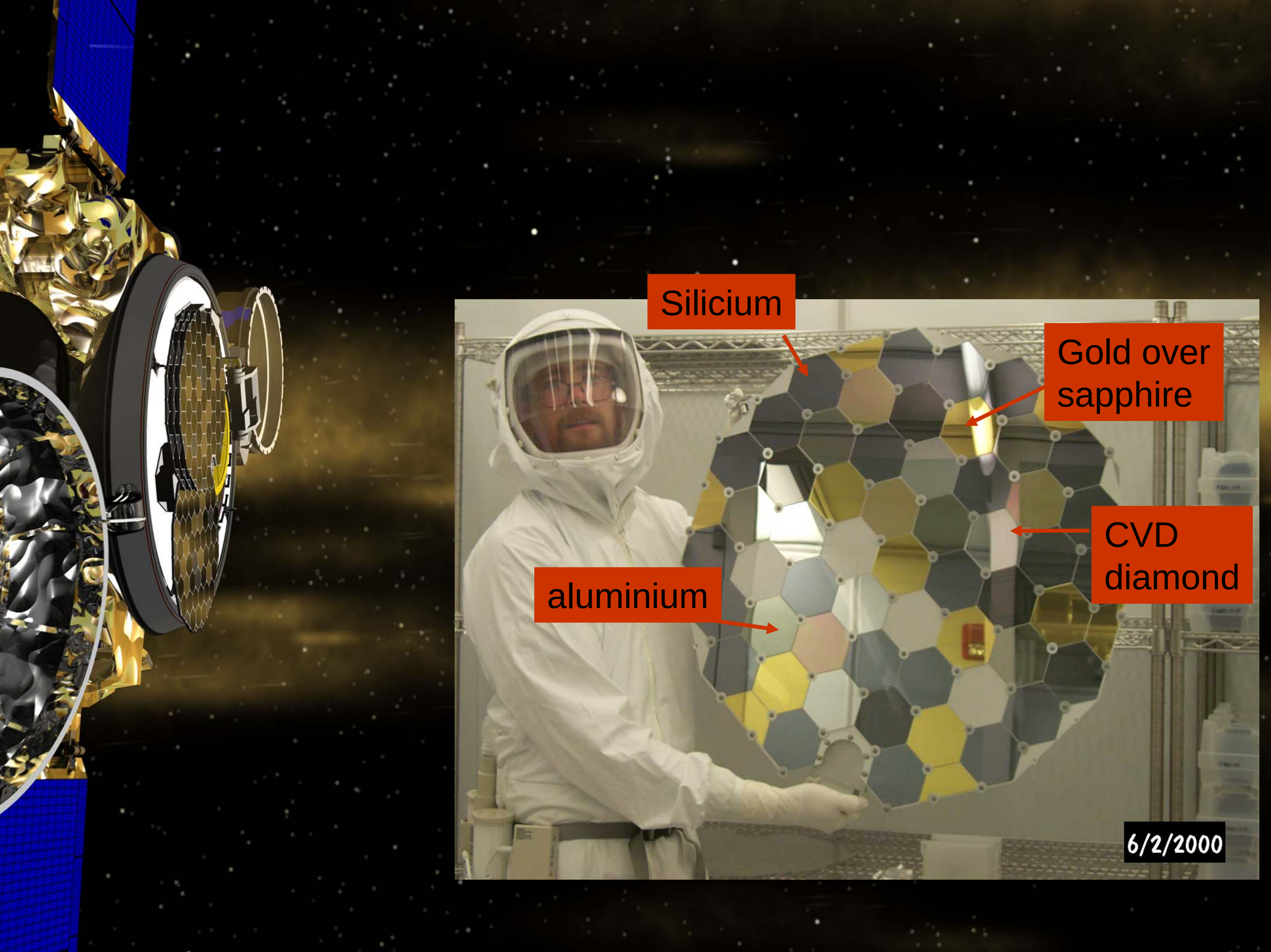
3- Noble gas isotopes



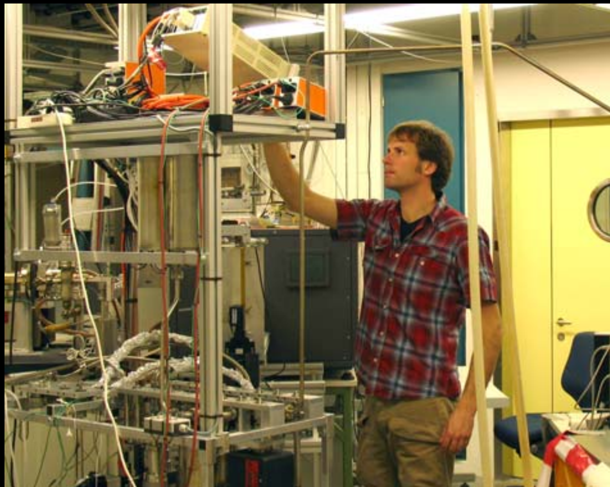


Sun

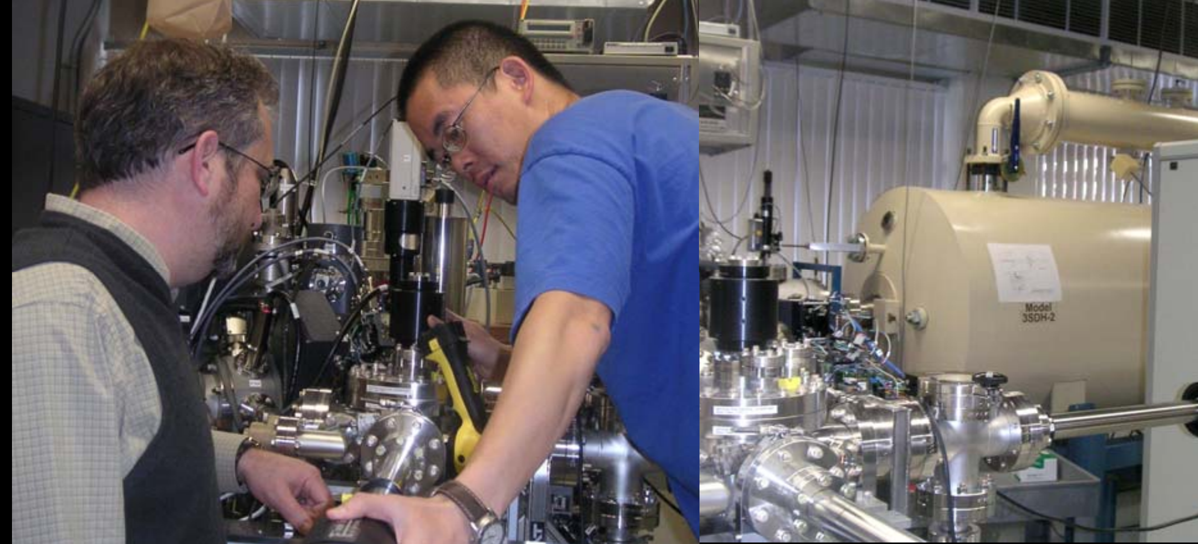
Solar wind


Silicium
Gold over sapphire
CVD diamond
aluminium
6/2/2000

Sept. 8, 2004

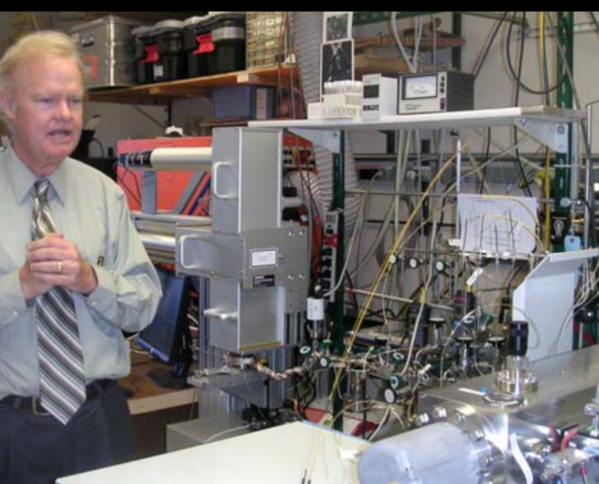


Acid attack under vacuum (Zurich)

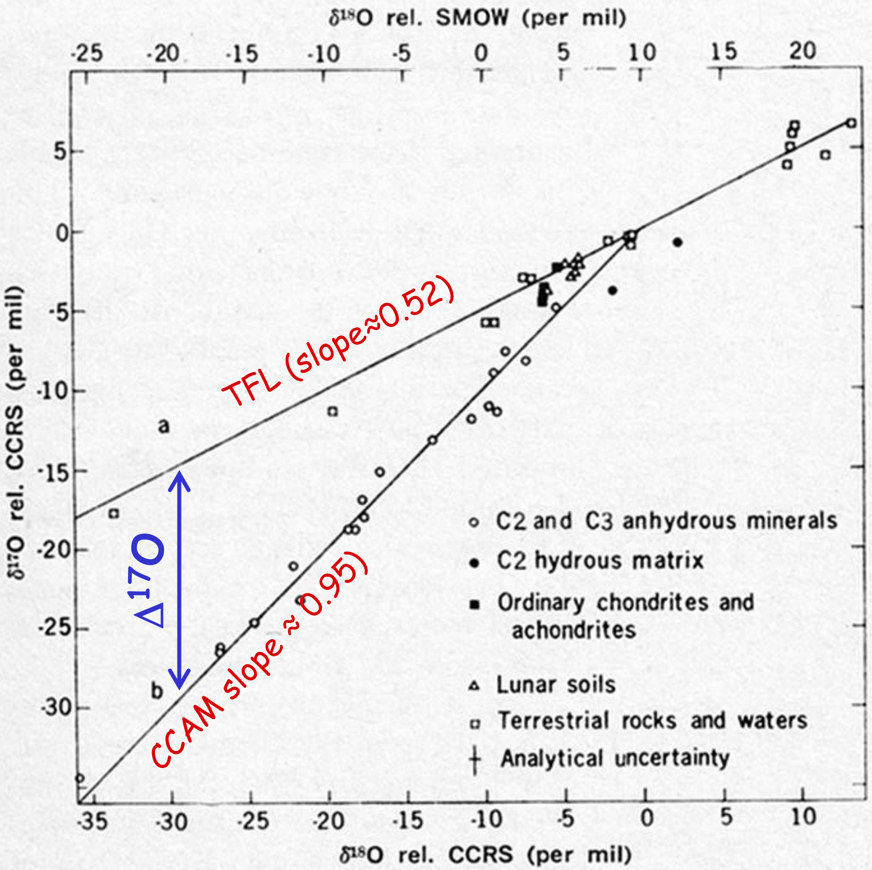


Megasisms (Los Angeles)

Laser ablation (Milton Keynes & Nancy)



Fluorination
(San Diego)



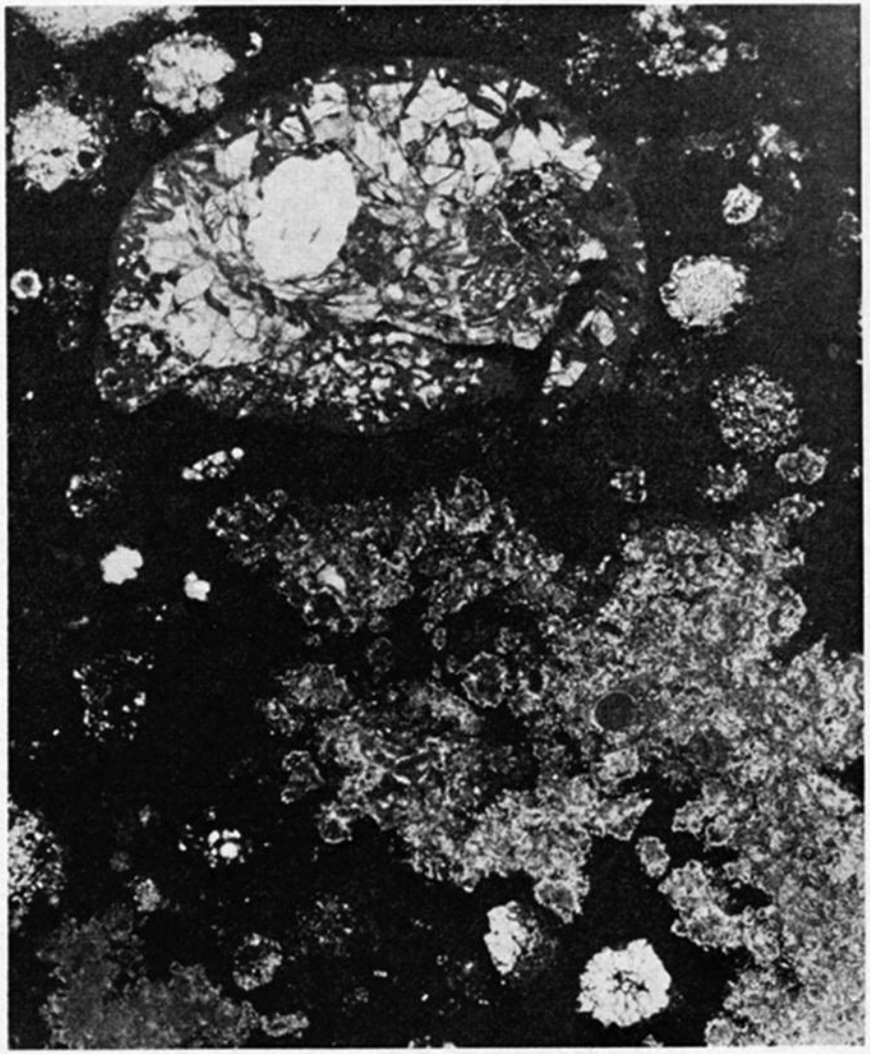
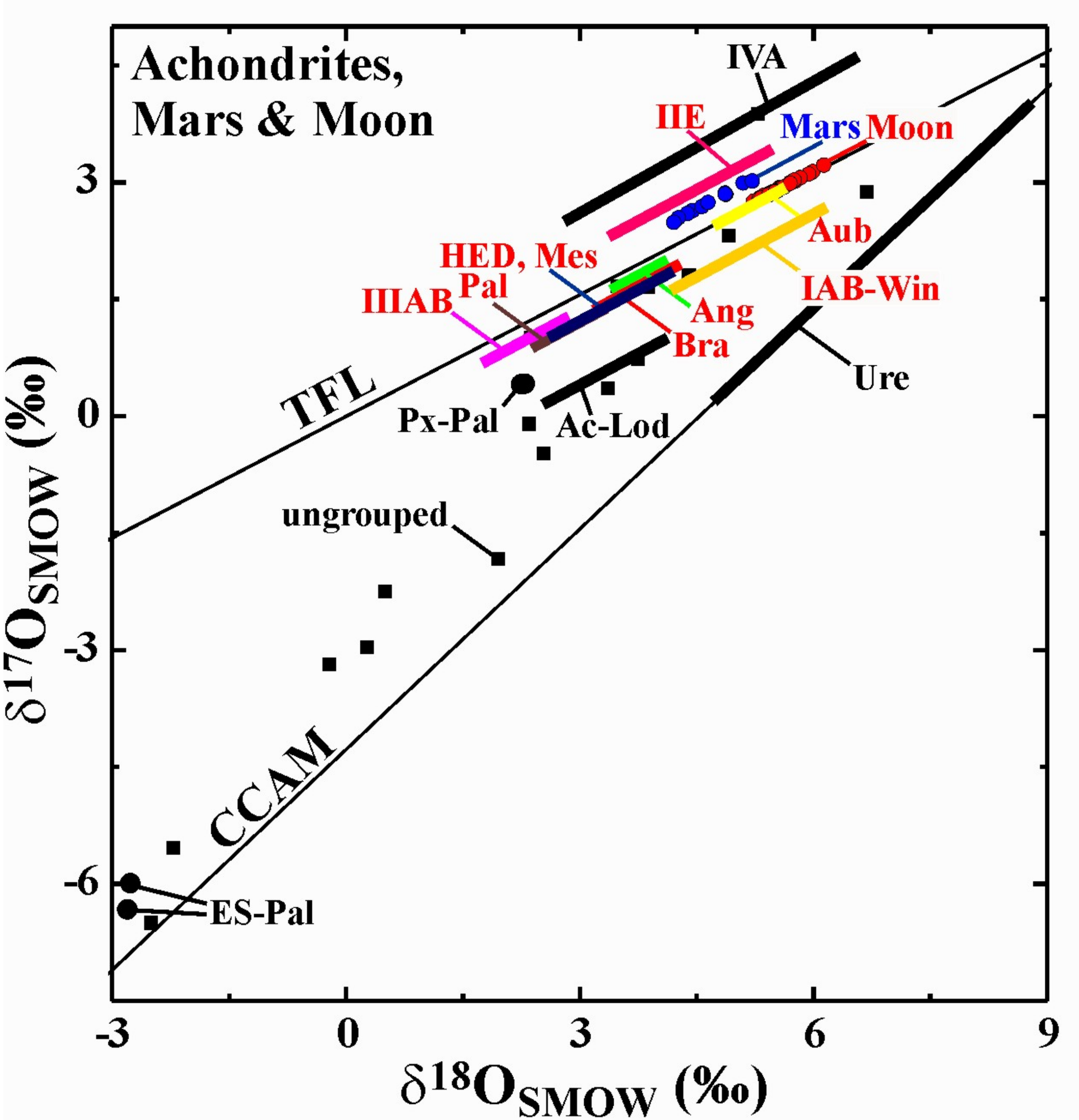


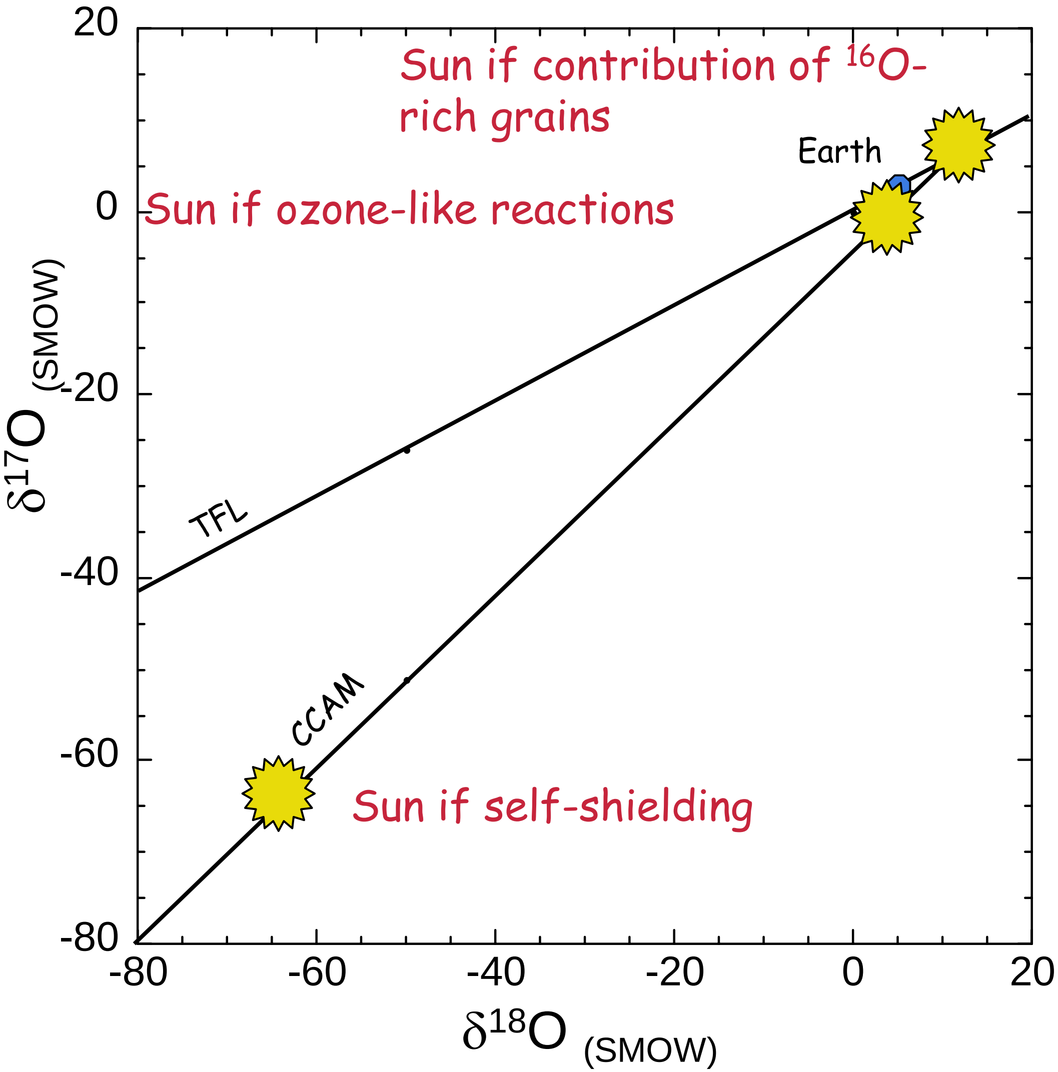
Fig. 1 (left). Relationship between $^{17}O/^{16}O$ variations and $^{18}O/^{16}O$ variations for terrestrial, lunar, and meteoritic samples. Points lying along line a, with a slope of +½, define the trend for chemical isotope effects; points lying along line b, with a slope of +1, define a mixing line between "normal" oxygen and an ^{16}O-rich component. The points on line b are all from phases in carbonaceous chondrites. The reference standards are SMOW [standard mean ocean water (*13*)] and CCRS [carbonaceous chondrite reference standard (see text)]. Fig. 2 (right). Photomicrograph of a section of the Allende meteorite, showing two large white inclusions (see text). Area of section, 8 by 10 mm. [Courtesy Richard J. Kjarval, Graphic Arts Facility, Physical Sciences Division, University of Chicago]

Clayton, Grossman & Mayeda (1973)



Achondrites,
Mars & Moon
IVA
IIE
Mars
Moon
Aub
IAB-Win
HED, Mes
Pal
IIIAB
Ang
Bra
Ure
TFL
Px-Pal
Ac-Lod
ungrouped
CCAM
ES-Pal
3
0
-3
-6
-3
0
3
6
9
δ17OSMOW (‰)
δ18OSMOW (‰)

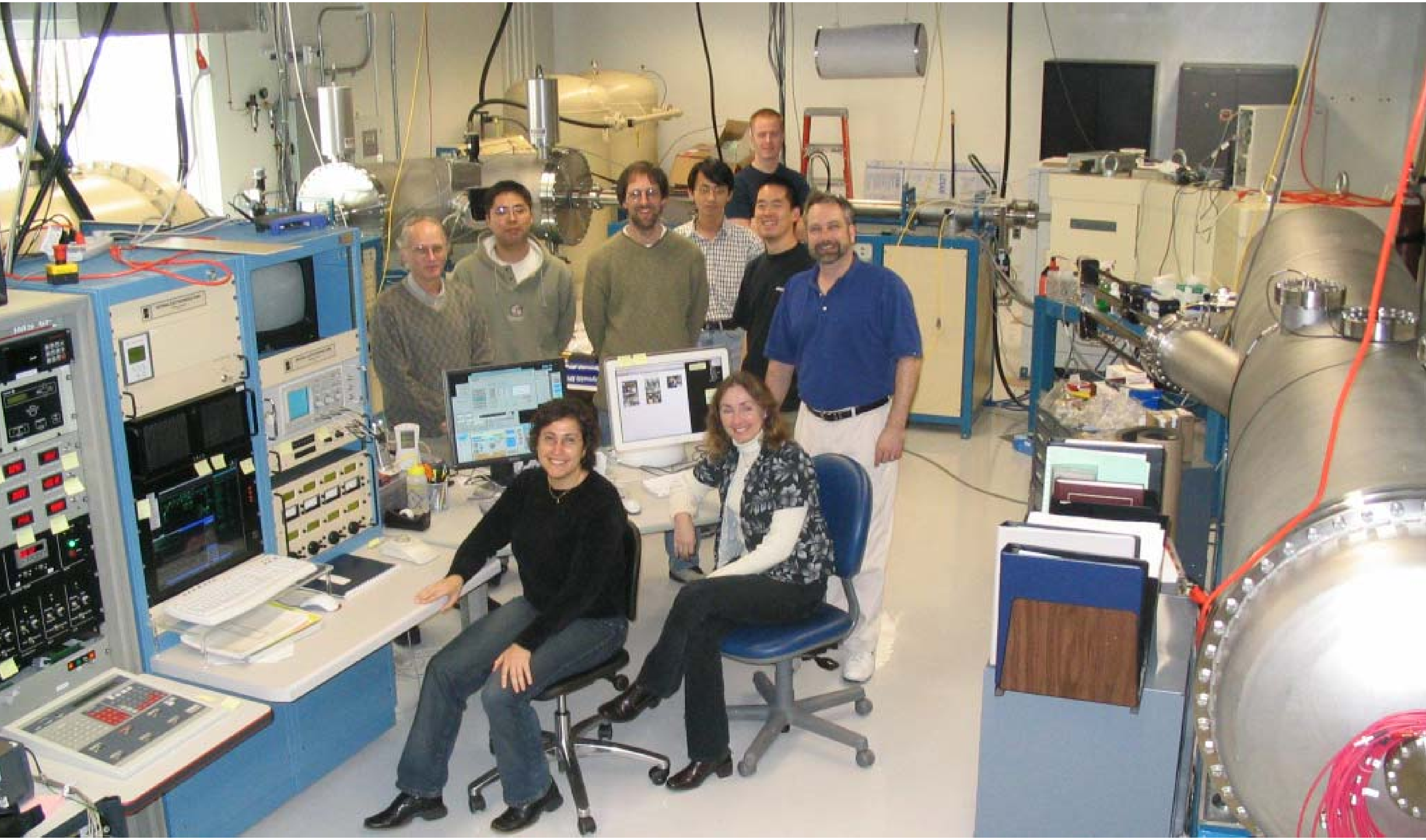
Origin of oxygen mass-independent isotopic variations (observed both at the microscale and at planetary scale ?)

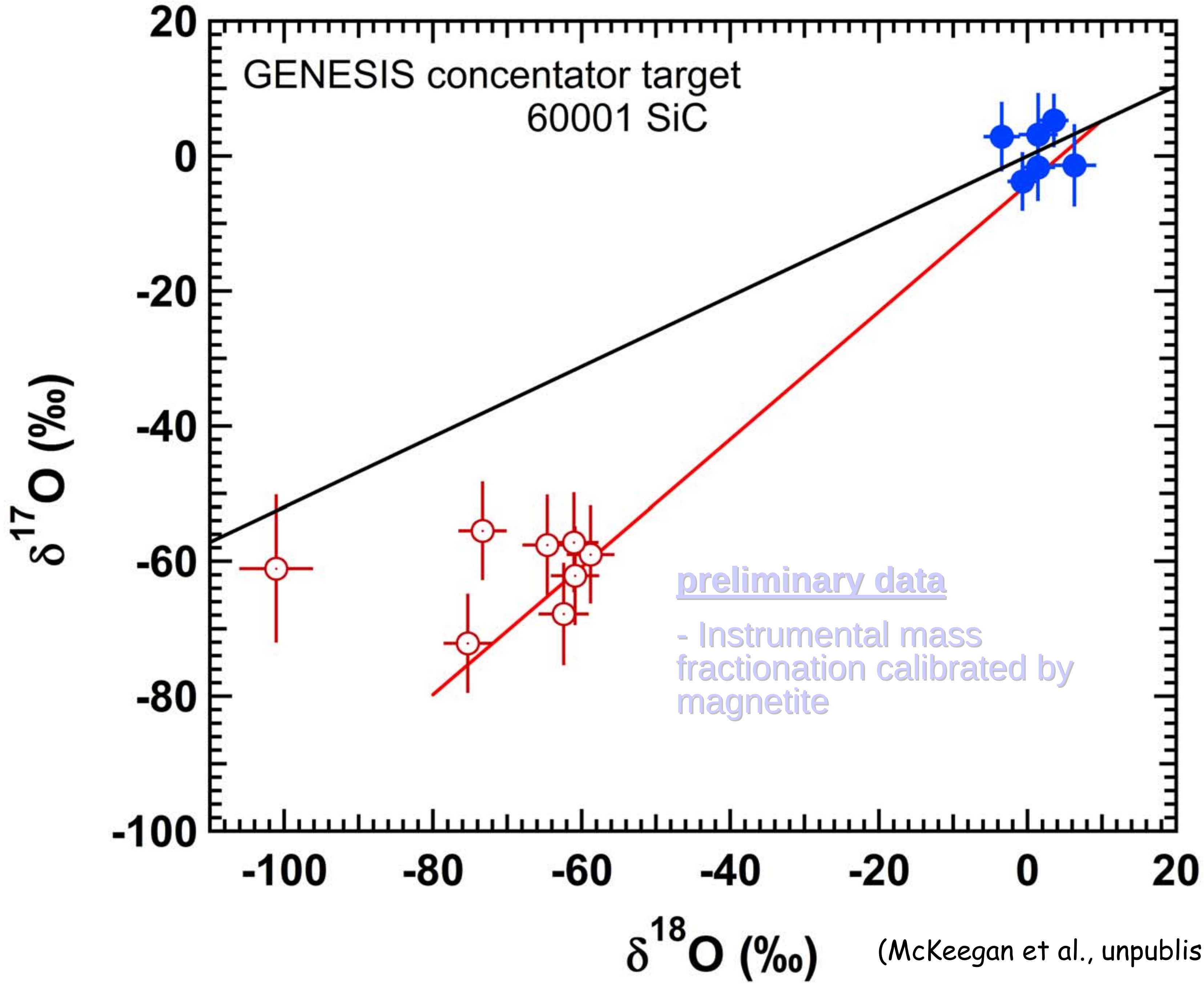


(1) : mixing of the disk with a ^{16}O-rich presolar component (Clayton et al., 1973)

(2) : mass indepnedent reactions (ozone-type or self-shielding (Thiemens & Heidenreich, 1983) (Clayton, 2002)

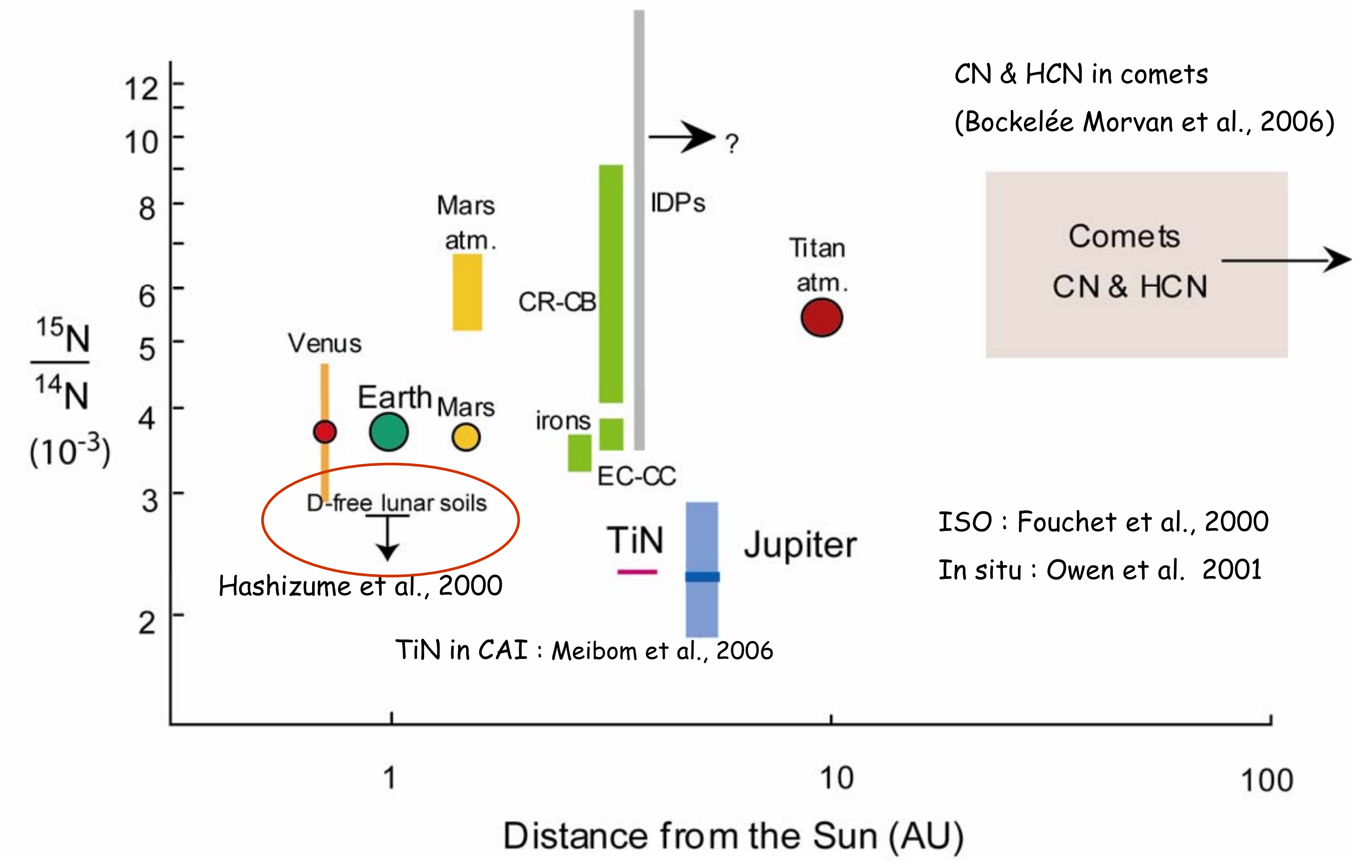
UCLA MegaSIMS laboratory





(McKeegan et al., unpublished)

Nitrogen isotope variations in solar system objects and reservoirs

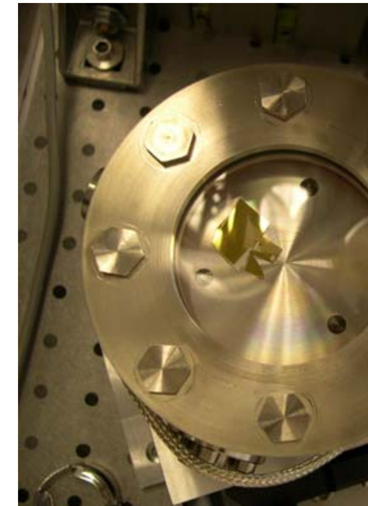


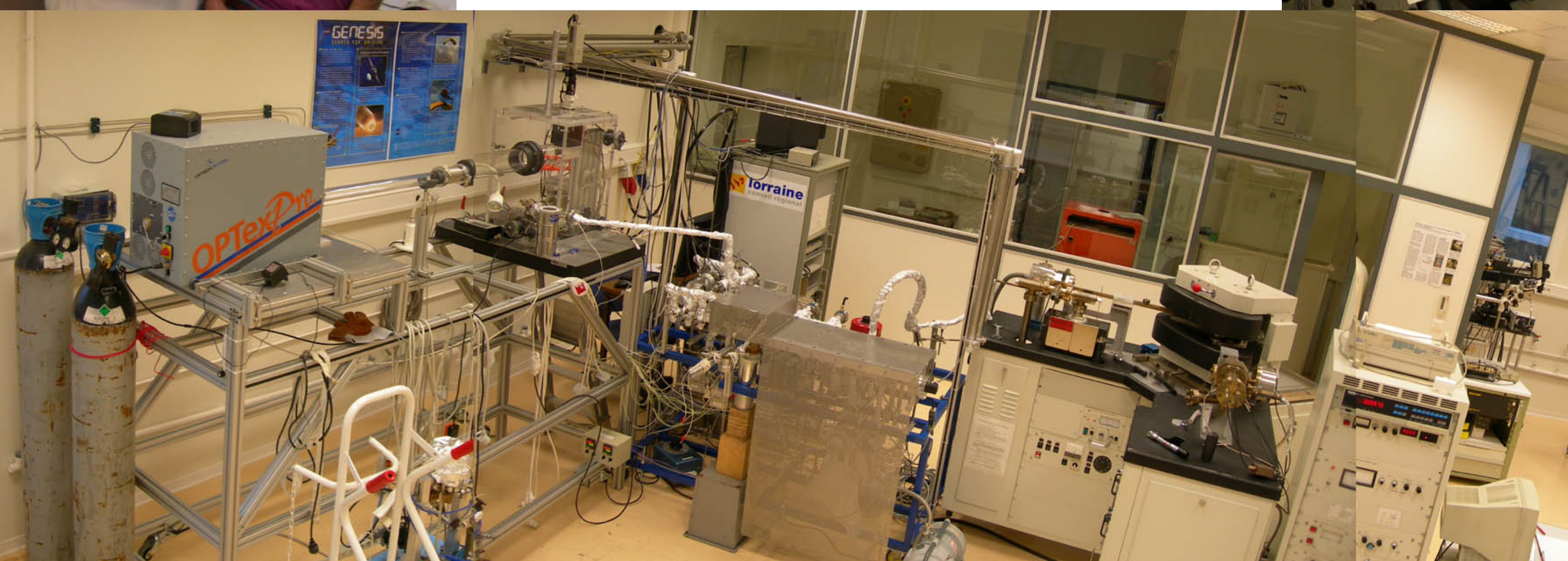
Nitrogen extraction : ablation laser (193 nm)

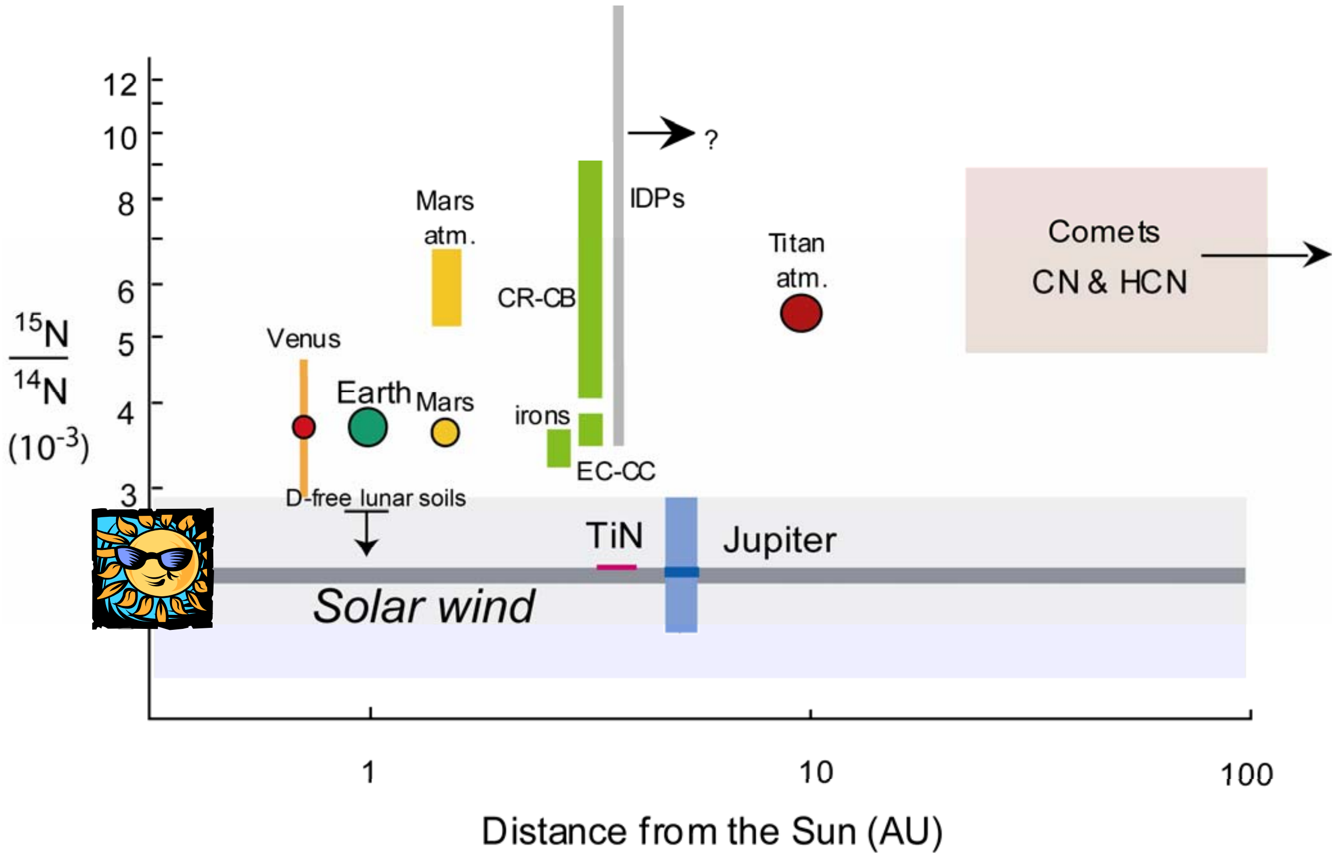
Laurent Zimmermann

Pete Burnard

- Static mass specgrometry
- He, Ne, N, Ar
- 26 months to decrease N blank to 4×10^{-13} mol N_2







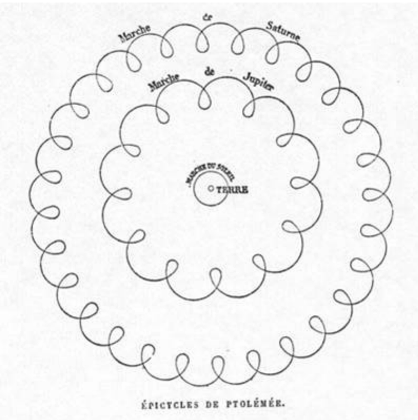
12
10
8
6
5
4
3
15N / 14N
(10-3)
Venus
Earth
Mars
Mars atm.
CR-CB
irons
EC-CC
IDPs
?
Titan atm.
Comets
CN & HCN
D-free lunar soils
TiN
Jupiter
Solar wind
1
10
100
Distance from the Sun (AU)

The solar system formed from an homogeneous disk

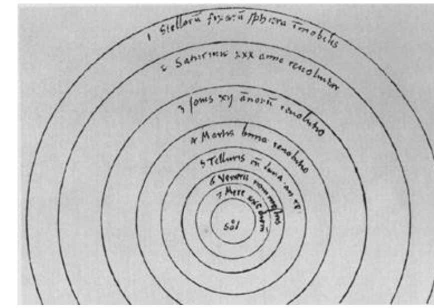
For N and O (and H), all cosmochemical reservoirs except Jupiter are anomalous

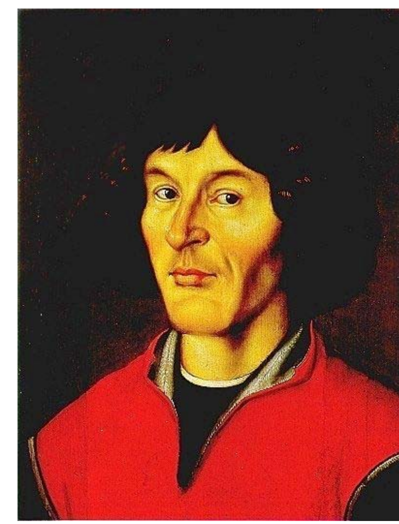
Processes responsible for such huge isotopic variations are central in the early evolution of the solar system

Further investigations of primitive objects are required to understand (i) origin of matter, (ii) large-scale processing in early solar system, and (iii) relations among solar system reservoirs and objects

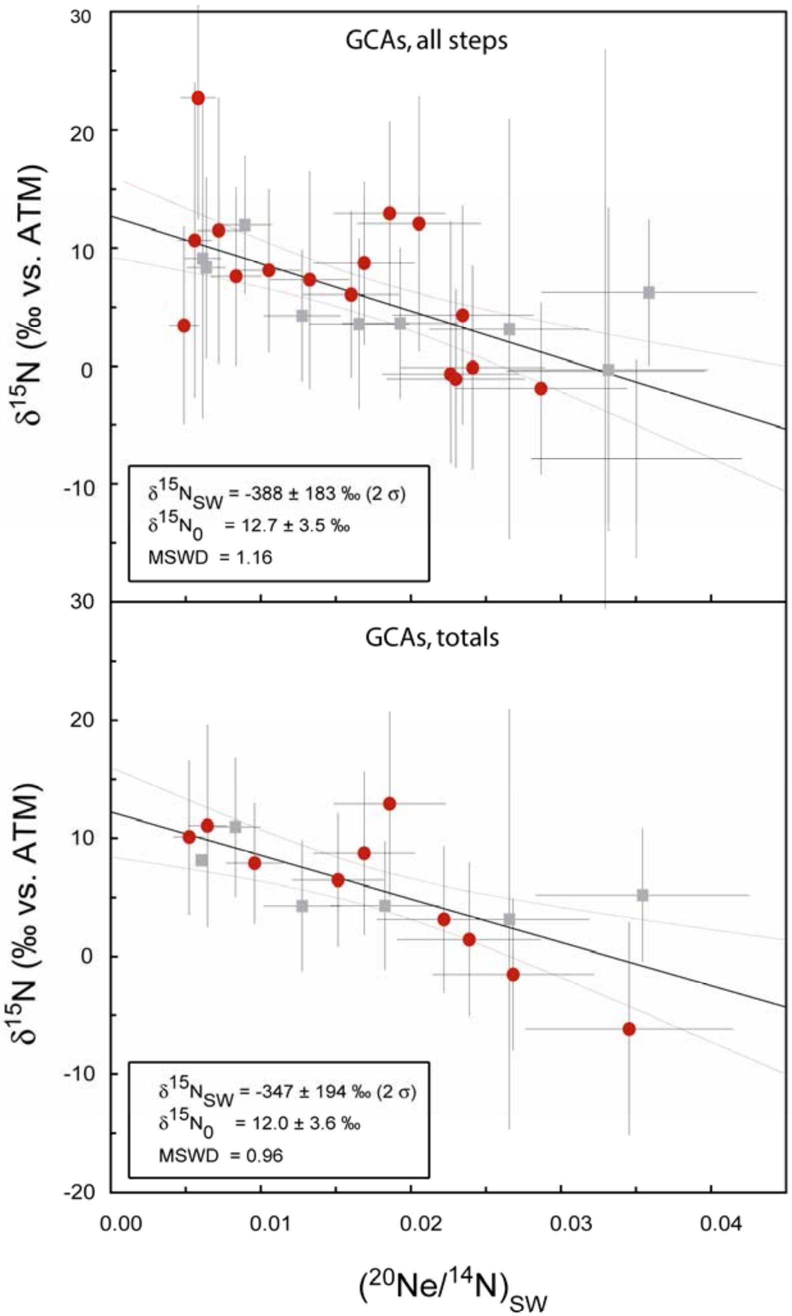


Ptolémée 90-168.





Nicolas Copernic (1473-1543)



Variations isotopique de N : mélange entre azote contaminant et azote solaire

Droite de mélange : $\delta^{15}N$ versus $^{20}Ne/^{14}N$ normalisé au rapport du vent solaire (1.14, mesuré directement)

Correction pour le fractionnement dépendant de la masse : seule la fraction de N solaire (< 4 %) est corrigée, correction isotopique inférieure à 3 ‰

(1) Pôle contaminant identique à celui mesuré sur le même support n'ayant pas volé

(2) Pôle solaire : $\delta^{15}N$ = -400 ‰